FURTHER STUDIES IN TERRESTRIAL RADIATION [1]

By G. C. SIMPSON, C. B. F. R. S., F. R. Met. Soc.

The results obtained in this paper are so different from those obtained in the previous paper, *Some Studies in Terrestrial Radiation*, that it is necessary to review the whole position, to find the causes of the differences and to estimate their significance. The chief difference in the procedure adopted in the two papers is that in the former we assumed that water vapor absorbs like a gray body; that is, the absorption is the same for all wave-lengths greater than 2 μ; while in this paper each wave-length has been assigned its appropriate absorption.

The former method may almost be dignified by the adjective classical. It was used in all the papers which have laid the foundation of our ideas on terrestrial radiation, among other by Humphreys.[2] Gold (in part),[3] Emden,[4] Hergesell,[5] and Mügge.[6] While most of the previous writers approached the problem from considerations of radiative equilibrium, Hergesell and I approached it from the point of view of the existing distribution of temperature and water vapor, and calculated the radiation which would result from these conditions without any consideration of how the temperature conditions are maintained.

Two outstanding results followed from my previous paper which are now shown to be wrong, because of the assumption that water vapor absorbs like a gray body. These are (*a*) the outgoing radiation originates in the layers of the atmosphere which have temperatures between 220° a and 286° a, and therefore are well within the troposphere; and (*b*) the stratosphere provides an insignificant amount of terrestrial radiation. The new investigation shows that with clear skies in middle latitudes the radiation is provided by the surface, the atmosphere and the stratosphere in the following proportions: From the stratosphere alone, 38 per cent; from the surface alone, 32 per cent; and from the surface atmosphere and stratosphere in different proportions, 30 per cent. The proportions are slightly different in different latitudes, while with overcast skies, the contribution from the ground is replaced by a smaller contribution from the clouds.

The new results affect previous work materially. Emden found that the stratosphere sends no radiation downwards, and of course the same result came out of my previous work. The new investigation shows that the stratosphere sends on the average a downward flux of longwave radiation of more than .120 cal./cm.^{2}/min., which is more than 43 per cent of the effective solar radiation. This agrees with the observations made by Angström on mountain peaks and in balloons, which revealed a downward radiation of between .13 and .16 cal./cm.^{2}/min. at heights between 4,000 and 5,000 metres, where, according to Emden,[7] there should have been less than .05 cal./cm.^{2}/ min.

Any radiation which the stratosphere sends downwards has to be sent out again, therefore this amount has to be added to the flux of terrestrial radiation which would be necessary to return the effective solar radiation alone. In other words, the effective solar radiation being .278, the outgoing radiation crossing the base of the stratosphere must be $>.278 + .120$, *i. e.* $>.398$ cal./cm.^{2}/min. Emden and Humphreys have derived expressions which purport to give the temperature of the stratosphere from considerations of the radiation crossing the base of the stratosphere. Both have neglected the long-wave radiation from the stratosphere which crosses its lower layers just as the terrestrial radiation crosses them, but in the opposite direction. Both have assumed grey or nearly grey radiation, so neglecting the fact that a large proportion of the terrestrial radiation is not absorbed at all by the stratosphere. In so far as both Emden and Humphreys simply equate the amount of energy absorbed to the amount emitted their methods are correct in principle; but as the numerical values they employ far from represent the facts, their results are of little value. It is little more than a coincidence that the expressions used by these investigators give even an approximate value for the temperature of the stratosphere.

The lesson to be learnt from this work is that totally misleading results follow from the assumption that water vapour absorbs like a grey body, and that even qualitative results can not be obtained on that assumption.

Many problems of atmospheric radiation have apparently been solved by the use of this assumption, and in all these cases the problems must be reexamined using the known absorption of water vapour in the various wavelengths. At present we have no satisfactory answers to any of the following questions:

(*a*) Why does not the temperature in the stratosphere decrease with height?

(*b*) Why does the temperature of the stratosphere increase as we pass from low to high latitudes?

(*c*) Why is the base of the stratosphere higher over equatorial than over polar regions?

The answer to the first problem will probably involve consideration of the high temperatures, at 40 to 50 kilometres above sea level, which we now associate with the ozone layer; this was not mentioned by Emden, but was referred to by Humphreys in his first paper on this subject.

As to the two latter questions we have as yet no solution in sight; but the controlling factor will probably be found to be in the dynamics of the troposphere rather than in the thermodynamics of the stratosphere.

SUMMARY

By using the observed temperatures of the earth's surface and of the stratosphere, and observed values for the absorption of coefficients for water vapour and carbon dioxide, approximate values have been obtained for the outgoing radiation from the earth and its atmosphere, and the laws governing nocturnal radiation have been indicated. Values have been found for the horizontal transfer of heat across the circles of latitude which is necessary to obtain radiative equilibrium of the atmosphere as a whole. The consequences of changes in the intensity of solar radiation have been investigated, and the conclusions drawn that change in cloud amount would be the chief agency by which radiative equilibrium would be restored. An increase in solar radiation would result in increased

[1] In March, 1928, Dr. George C. Simpson published as number 16 of Volume II of the Memoirs of the Royal Meteorological Society a paper entitled "Some Studies in Terrestrial Radiation."

He now publishes as number 21 of Volume III of the same series the results of fresh investigations on the same subject under the title "Further Studies in Terrestrial Radiation."

Inasmuch as the results of the later investigations differ somewhat from those reached in the early studies, the author's review and conclusions are printed in full. *Editor.*

The full paper can be obtained from Edward Stanford (Ltd.), 12, 13, and 14 Long Acre W. C. 2, London, at the price of 2 shillings and 6 pence. *Editor.*

[2] Humphreys, *Astrophysical Journal*, vol. 29, p. 14, 1909.

[3] Gold, *London, Proc. R. Soc.*, vol. 82 (A), p. 43, 1909.

[4] Emden, *München Sitzber. Bayr. Akad. Wiss.*, p. 55, 1913.

[5] Hergesell, *Lindenberg Arbeit. Preuss. Aero. Obs.*, vol. 13, Wiss. Abh.

[6] Mügge, *Zs. Ceophysik, Braunschweig*, vol. 2, p. 63, 1926.

[7] Emden, *Loc. cit.*, p. 129

cloud and precipitation, while a decrease in solar energy would lead to less cloud and less precipitation. The possibility of increased solar activity leading to an "ice age" is discussed.

Suzuki on fires and the weather.—The author [8] presents in this monograph of 73 octavo pages a vast amount of detailed experimental research, all of which bear witness to the thoroughness of the study. It is quite impossible with the space at command to present a comprehensive review of the various aspects of the research. I shall therefore confine my remarks to those phases of the subject that most appeal to similar studies in this country. Here forest fires only are studied with reference to the associated weather conditions. The author's study, on the contrary, has to do with conflagrations involving buildings, whether singly or in mass, as well as forest fires.

A large part of the statistical material of the study was accumulated through the very simple expedient of burning the ordinary incense stick sold in the shops of Japan. This stick is a thin cylinder with diameter nearly 1.45 mm. and made mainly of powder of fragrant wood and partly of pine resin used as paste. When the upper end is lighted and the stick held upright it burns down steadily without flame.

If conditions remain the same it continues to burn always at a uniform rate.

The incense stick is peculiarly sensitive to moisture and absorbs it readily when exposed to the air, thus five sticks so dried that their total weight was reduced to 1.159 g. when exposed to the air became gradually heavier and after an exposure of 3 hours and 40 minutes reached a maximum weight of 1.259 g.

The effect of the wind in the burning of an incense stick was thoroughly investigated by means of a wind tunnel and cleverly devised apparatus. It was found that the burning velocity 5.3 m/min. at dead calm rises to the maximum 6.3 m/min. when the air current strength becomes 110 m/min. and then gradually decreases until the current velocity rises to 220 m/min., when suddenly the fire in the incense stick goes out.

With respect to the variation of the water content of timber the author concludes:

> The weight of the timber varies in harmony with the change of relative humidity, only differing with regard to time. The time may be retarded by several hours, the actual amount of which depends on the manner of the variation of the humidity.

His conclusions with respect to other phases of the subject are summarized in the following paragraphs.—*A. J. H.*

SUMMARY

Burning every day several incense sticks through a year the author has found that they burn more rapidly in summer than in winter, whilst the daily variation of their burning velocity is subjected to the changing relative humidity of surrounding air. Further, using several other materials the influence of humidity on the burning together with house fires is thoroughly investigated, thus:

1. The most important factor of the problem among the numerous meteorological elements is the relative humidity.
2. The combustion of some substances is influenced, in large degree, by the variation of the water quantity within when they burn in low temperature without flame.
3. The combustion of some substances is influenced by the water quantity of air when they burn with flame and temperature is moderately high.
4. The combustion of other substances is, if temperature is enormously high, controlled by the humidity of air, but in the way contrary to the preceding; that is, they burn strongly with increasing humidity.
5. The influence of wind on fires is not so remarkable as it is now believed.
6. The fire statistics in many cities and prefectures in Japan indicates that the outbreak of fires has the most intimate correlation with the relative humidity among many other meteorological elements.
7. The outbreak of fires undergoes a change yearly and daily. It corresponds in many respects with the seasonal and daily variations of the moisture in timber, paper, and cloth, etc., in the room.

Therefore we can conclude that the relative humidity has the great influence not only on the burning but also on the fires.

Solar coronas of 1°, 2°, and 3° in very clear sky (by Eric R. Miller).—Instead of the usual bright glare around the sun, I was surprised to see three bright rings, exhibiting the colors of the spectrum, when I looked at the sky near the sun at 11:45 a. m., August 31, 1928. These rings were so easily seen that I pointed them out to a number of persons, all of whom saw them easily. They lasted until about 3 p. m., when increasing cirrus obscured them. I measured the red circles, which were most easily seen, and found the radii to be approximately 1°, 2°, and 3°. The rings were again visible on September 2.

The sky was unusually clear. The usual measurement of sky polarization with Pickering polarimeter at 8:18 a. m., August 31, when the zenith distance of the sun was 60°, gave a percentage of 77, which is unusually high.

My surmise is that these rings are a regular solar phenomenon, visible only when glare due to cloud, haze, and dust is absent. I have never seen them before, and recall no reference to them in the literature of meteorological optics. If they have been previously described, I should appreciate having a reference to the publication.

Recorded observations of the Hess ultragamma radiation at Muottas Muraigl (2,456 m.) (by *G. Hoffman* and *F. Lindholm*).—Summary: The increase in the ionising effect of penetrating radiation by the use of compressed carbonic acid gas for filling the ionisation chamber together with an electrometric compensating arrangement enables an accuracy of 1—2$^0/_{55}$ to be attained. Continuous records of penetrating radiation are carried out at Koenigsberg (at sea level) and at Muottas Muraigl (2,456 m.) in the Upper Engadine, with a lead screen for shutting out the softer rays from around. The intensity varies with the changes in barometric pressure, but in an irregular manner. No simple variation of intensity according to sidereal time exists. It will be possible to draw further conclusions only after new and extensive observations have been made. By measuring the absorption power of different protecting screens, diffusion effects are found which confirm the character of Hess radiation as ultra-γ-radiation.

METEOROLOGICAL SUMMARY FOR SOUTHERN SOUTH AMERICA, JULY, 1928

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During July the weather was relatively dry in central Chile and but little rainy in the regions farther south. This was due to two factors: (1) Diminished intensity of atmospheric circulation over the South Pacific and (2) deviation toward the south in the mean path of the depressions, which usually reach the coast between latitudes 40° and 45°.

Depressions crossed the extreme south during the following periods: 1st–4th, 5th–7th, and 14th–15th. The first and second of these storms brought rain as far north as Concepcion; the third was of little importance and

[8] Seitaro Suzuki, "The fires and the weather," Journal of the Department of Agriculture, Kyushu Imperial University, vol. 2, No. 1.